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Prediction of maize weevil population growth rate

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Abstract.
Insects play ecological roles within natural ecosystems, provide economic benefits in agricultural systems, act as pollinators and seed dispersers. But some infest grain, which can lead to catastrophic losses of food supplies, especially in developing countries. Grain is grown and used all over the world, but after grain is harvested, maintaining quality is important not only for human health, but for economic reasons as well. One of the main causes for grain deterioration, especially in warm tropical regions (as well as other developing countries), is insect infestation. In particular, this paper focuses on the maize weevil (Sitophilus zeamais). It is essential to understand growth dynamics and lifecycle of this pest in order to develop methods for controlling it This experiment focused to develop growth equation that can be used to predict the population density of the maize weevils. Weevils, yellow dent corn, lab jars, and a growth chamber which provided a controlled environment were used to study population growth of the maize weevil. Results showed that the population density followed an exponential growth with a growth constant range of 0.0392 to 0.0448. Maize weevils for future research work were raised.

Keywords: *Insect, grain, developing countries, maize weevil, dent corn*

Introduction

Arthropods

Arthropods under the kingdom Animalia are of the jointed limbed animals to which insects belong. Arthropods play ecological roles within natural ecosystems, provide economic benefits in agricultural systems (Wilson 1987; Isaacs et al. 2009), act as pollinators and seed dispersers (Wilson 1987; Isaacs et al. 2009; Bond & Slingsby 1984), and they help in decomposition and nutrient cycling to enrich soils for good plant growth (Seastedt & Crossley 1984). Insects possess tremendous reproductive potential, survival capacity and diversity that make them successful inhabitants on earth (Morgan & Miller 2004). Insects occupy almost every ecological

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niche and they may be beneficial to human activity. However, some are harmful to man, animals, crops and stored products, and can wreak such havoc as to impose threats to other living organisms on a massive scale.

Beetles

Beetles are members of the insect order coleoptera, comprising approximately one quarter of all the animals currently in existence (New 2009). According to Crowson 1982; and Grimaldi & Engel 2005, beetles are believed to have been in existence for 285 million years. Ponomarenko 1995 reported that the oldest beetle fossils are from the lower Permian taxa (265 million years). Beetles have been successful for thousands of years due to their reproductive abilities and habits, and they do communicate to each other by different ways such as, use of chemicals (e.g. pheromones), sounds (e.g. stridulating), or by visual displys (e.g. fireflies). The adult beetles select a spot for eggs that will provide the hatched larva with sufficient food once it has emerged from the hatched egg. One example of this is the maize weevil which oviposit their eggs into kernels of grain. With all the adaptations of beetles, “humans live in age of beetles” (New 2009; Arthur & Hogue 2004).

Maize Weevils

Maize weevil, (*Sitophilus zeamais*), is a species of beetle in the family Curculionidae that is a pest of maize especially during the drying and storage periods of grain production. Maize weevils are approximately 2.5 to 4 mm in length with a brown color (Fig 1). The average lifecycle is on average 36 days at 27±1^{0}C, and 69±3% relative humidity (RH) (Sharifi & Mills 1971). An adult female can lay about 300 to 400 eggs over a period of 4-5 weeks (Hill 1983). Maize weevils can be extremely economically destructive to maize under good conditions of temperature and maize moisture content. Adult weevils damage grain by feeding on the endosperm or starchy areas of the grain kernel. The female deposits an egg into the previously-consumed portion of the kernel. Eggs hatch into tiny grubs which feed on the endosperm inside the kernel (Hill 1983). This impacts the quality of the grain in terms of bulk density, moisture content and starch value while also producing a considerable amount of grain dust. Given enough time, weevils will completely consume maize during storage. Exposure due to damage inflicted on the kernels also facilitates disease and fungal growth in the grain (CGC 2013). Numerous factors like diet and variety difference within grains have been reported to affect the development time and reproductive capacity of maize weevils (Adams 1976; Dobie & Kilminster 1978; Gomez et al. 1983).

Figure 1: Maize weevil (Laden 2008)

Maize/corn Production

Maize (*Zea mays*), or corn, is one of the world’s most widely produced and used grains. In 2011, more than 883 million Mg of corn were produced worldwide (FAOSTAT 2013). Different types of corn are grown worldwide including flint, dent (Fig 2), floury, waxy, pop and sweet corn. Corn is a versatile grain in the sense that it is grown all over the world in countries such as the United States, Argentina, Brazil, Canada, China, European Union, India, Mexico, Ukraine and South Africa (NCGA 2013; USDA 2013). In the U.S alone, corn production has increased from 1.6 Mg/ha in the 20th century to 9.5 Mg/ha in the 21st century, on average, due to the development and wide spread use of new farming technologies such as hybrid corn, synthetic fertilizers and farm machinery (Edgerton 2009). As the demand for corn grows at approximately 2.2% per year, many developing countries are actively growing corn as well (Fran 2012). The main use for corn in developing countries is for human consumption (IITA 2009).

Figure 2: Yellow dent corn (USDA, 2012)

Not only is corn grown for direct consumption, it is also used for ethanol production and as an industrial feedstock in many developed countries. Overall, there are approximately 4,200 different uses for corn products with the potential for more (NCGA 2012).

It is important that corn remains at a high quality after harvest and during storage, and to minimize potential loss and damage due to a multitude of factors such as pests, disease, damage and rapid deterioration. Improvements in storage facilities and producer education help decrease these issues. In developing countries, however, this can be challenging. The quality of the corn is limited by the production, storage conditions and damage/pest control available in these areas and can have severe economic impacts.

Need for Research

The maize weevil damages corn and can have an extreme economic impact for the producer after harvest during storage. On-going studies are being done to see what can be improved to diminish the population and the effects that maize weevils have on the grain. Thus there is a need for large scale rearing of maize weevils.

The objectives of this study included:

- Rear maize weevils at different population densities in yellow dent corn in order to raise thousands to be used in future research work.
- Develop growth equations that can be used to predict the population density of the weevils.

Material and methods

Containers

Containers used in this experiment were one pint (500-mL) glass canning jars. For this experiment, 36 jars were thoroughly cleaned, dried and weighed before being used. The jars were then fitted with canning rings and a flexible mesh, instead of the standard canning lid, to allow for air movement while keeping the weevils contained within the jar during the experiment.

Maize
Maize used for this experiment was Fontanelle 6T210 2012. It was collected, visually observed, and measured for moisture content (with a result of 13.1% on average). The corn was then measured into each of the 36 jars at 256 g per jar. The filled jars were then placed into the preheated chamber at 270C for 24 hours in order for the corn to acclimate to the desired temperature.

Maize Weevils
The maize weevils for this experiment *(S. zeamais)* were obtained from an infested container of corn in the biomaterials laboratory at Iowa State University. The weevils were separated and retrieved from the infected corn through sieving. A screen of 0.99 mm (2.5/64 inch) diameter retained the weevils, whereas 4.76 mm (12/64 inch) retained the corn. Fines were collected at the bottom. Weevils were weighed on a scale with a sensitivity of 0.01 g, but did not register a weight. Therefore, it was concluded that the weight of the weevils in each jar were negligible for this experiment.

Experimental Procedures

After a sufficient number of weevils were collected, they were counted out into the required population densities of 50, 100, 300 weevils/kg. With each of our jars containing 265 g of corn, on average, populations were reduced to 14, 27, 80 weevils/jar. The jars were then weighed and labeled according to the desired population density, replication number and time frame. The time frames were 14, 28, 42, and 56 days or (2, 4, 6 and 8 weeks) with three replications of each population density per time frame. Population densities were identified as follows: A=50 weevils/jar, B=100 weevils/jar, C=300 weevils/jar. A jar labeled A-1-2 has a population density of 50 weevils/jar, is the first replication of the time period of 2 weeks (14 days) after inoculation. An example of the labeling is shown below in Figure 3.

Figure 3: Jar label

Initial data were recorded and all of the jars were placed into the chamber at 27^0C. Every fourteen days, the proper nine jars were removed from the chamber (three reps from each population density). The jars were examined one at a time. The weevils were separated through sieving and the population was documented. Both live and dead weevils/jar were recorded, as well as the weight of the remaining corn in the jar. Corn moisture content for each jar was also measured and recorded. Live weevil counts were normalized to weevils/kg DM (Dry Matter) of maize.

Data Analysis

Once all of the necessary data were collected, graphs were produced using Excel and formal tests and comparisons were conducted with JMP Pro 10 software. Tests included Analysis of Variance (ANOVA), and mean comparisons of live weevils using Turkey's test.

Results and discussion

Maize weevil results

Growth results

This maize weevil experiment was designed to develop an optimal starting population density and observable growth rate model in order to raise thousands of maize weevils for future experimental use. Data were collected every fourteen days (two weeks) from inoculation to the end of the experiment at eight weeks (Fig 4). Generally, there was an observable increase in the number of live weevils compared to the initial inoculation population, as shown in Fig 4. During the lag phase, i.e. after fourteen and twenty-eight days, there was no increase in the number of weevils and this was attributed to weevils having spent less than thirty-six days of the average life cycle (Sharifi & Mills 1971). At 46 and 56 days there was an exponential increase in the number of weevils, probably due to the presence of food and no competition. Boller 1972; Aluja et al. 2001 emphasized the importance of oviposition in insects in which female reproductive performance is regarded as an important determinant of oviposition dynamics, and whatever affects oviposition affects reproductive output at the end. In this experiment, oviposition was not negatively affected. The trend followed what was reported by Boller 1972; and Haines 1991 for insects.

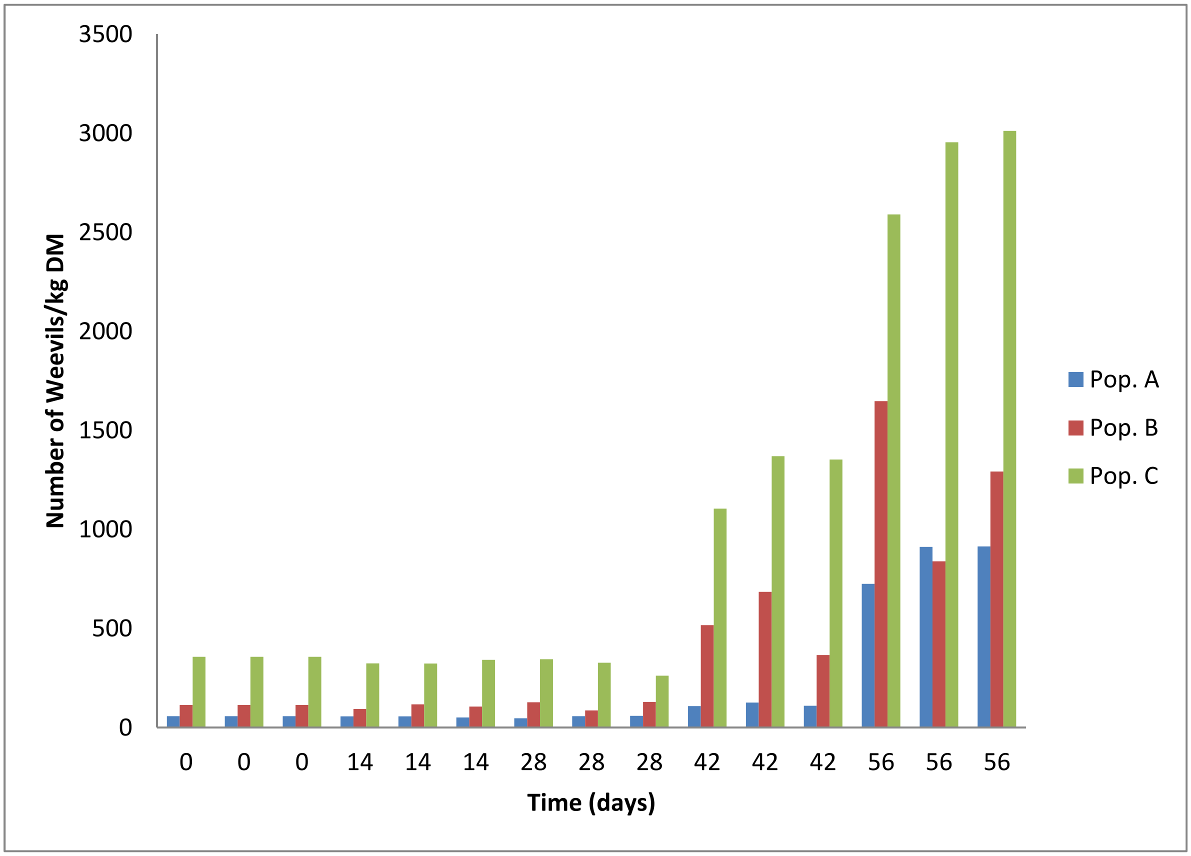

Figure 4: Number of counted live weevils over time for different densities.

Success in laboratory rearing of insects was reported by Krebs 2009 since they do not encounter competition from other species. Cowley et al. 1980; Rugumamu 2009 also observed an increase in weevil population when they kept them alone as compared to keeping them with other species like *P.truncatus,* which further suggests why the experiment was successful. Similar trends were also observed by Fragoso et al. 2005.

Growth modeling

Modeling to predict the growth of each population density was done, plus an overall equation for all population densities combined together was developed (Fig 5). Population growth was modeled as an exponential function.

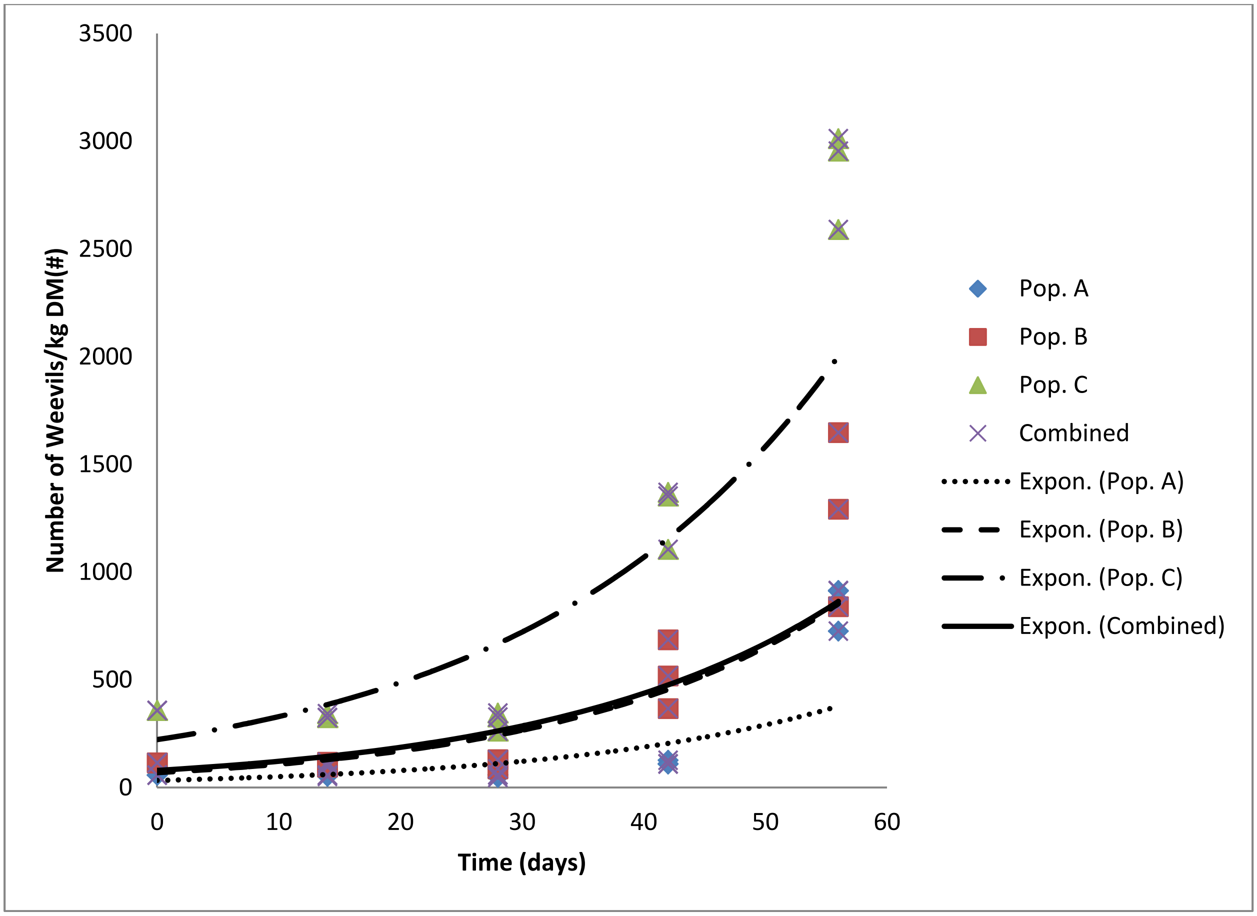

Figure 5: Live weevils over time for different densities.

The developed models were in the same form as that reported by (Haines 1991) (Equation 1) for exponential growth of insects:

$$P_t = P_o\, e^{rt} \tag{1}$$

Where;

P_t = Number of insects at time t,

P_o = Initial number of insects at time zero

r = intrinsic increase of population

The resulting equations were:

$$P_a = 32.991\, e^{0.0435t} \qquad R^2 = 0.6687 \tag{2}$$

$$P_b = 69.2851\, e^{0.0448t} \qquad R^2 = 0.766 \tag{3}$$

$$P_c = 222.51 e^{0.0392t} \qquad R^2 = 0.7508 \tag{4}$$

$$P_{all} = 79.823\, e^{0.0425t} \qquad R^2 = 0.4674 \tag{5}$$

Where subscripts a, b, c and all represent starting population densities A (50 weevil/Jar), B (100 weevils/jar), C (300 weevils/jar), and all data combined, respectively. The population density of B (100 weevils/jar) yielded the highest R^2 value of 76.6%, followed by C (300 weevils/jar) with an R^2 value of 75.08%.

Inferences about population variances

One-way analysis (ANOVA) for the number of live weevils/kg DM found a p-value of 0.0105 at α=0.05. The box plot showed right skewedness (Fig 6) thus departure, from normality, and according to (Conover et al. 1981), the Brown-Forsythe-Levene (BFL) test was appropriate with regard to Hartley's test for inference about population variances:

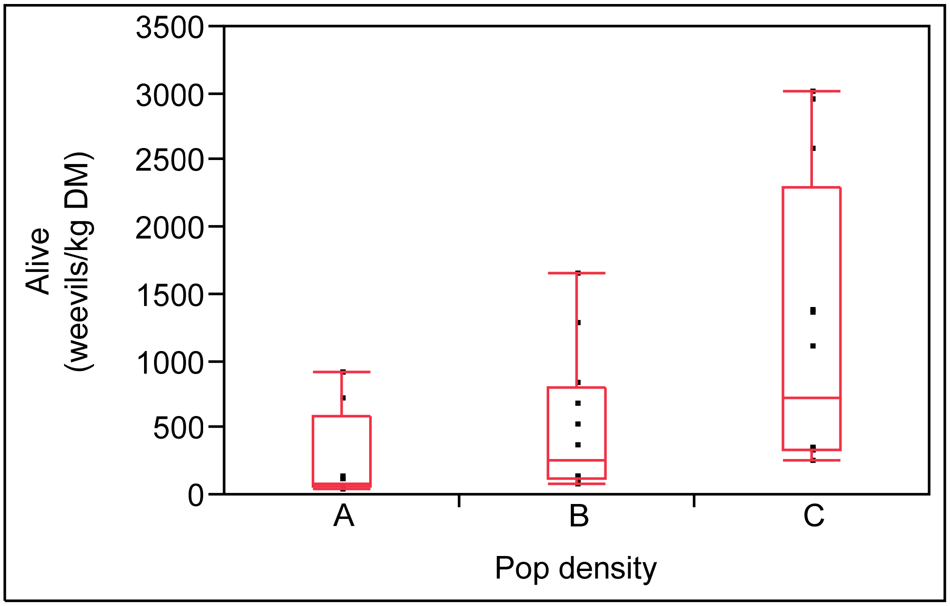

Figure 6: Box plot for live weevils.

H_o: $\sigma^2_A = \sigma^2_B = \sigma^2_C$ vs. H_a: $\sigma^2_A \neq \sigma^2_B \neq \sigma^2_C$

Results for the test that variances were equal (Fig 7) showed that the Levene test p-value was 0.0156 at α=0.05, thus rejecting the null hypothesis (H_o) at α=0.05, which meant that there is sufficient evidence of a difference in population variances for the three population densities.

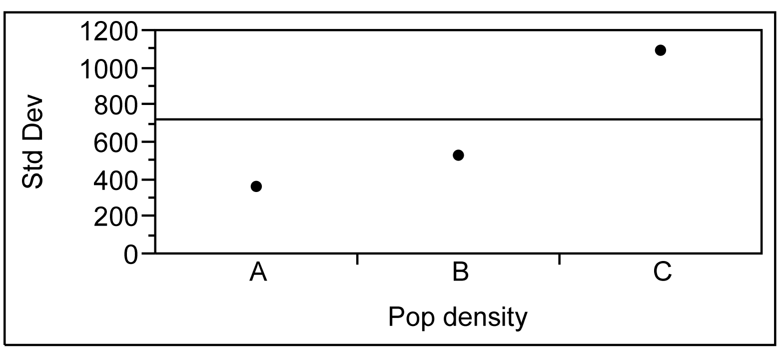

Figure 7: Testing equal variances

Tukey's mean comparison

Comparing the population densities, it was found that Treatment C (300 weevils/jar) was non-significantly different from B (100 weevils/jar), and B (100 weevils/jar) was non- significantly different from A (50 weevils/kg) but Treatment C (300 weevil/kg) was significantly different from A (50 weevils/kg) (Table 1), with a p-value of 0.0103 at α=0.05. This analysis was helpful to understand whether the population density means were different from each other. Tukey's procedure was used because according to (Longnecker 2010), it's more conservative than Fisher's LSD (i.e. it tends to be more resistant to falsely declaring significance).

H_o: $\mu_A = \mu_B = \mu_C$ vs. H_a: $\mu_A \neq \mu_B \neq \mu_C$

Table 1: Tukey's mean comparison of different population densities

Level		mean
C-Treatment (300 weevil/jar)	x	1193.08
B-Treatment (100 weevil/jar)	x y	501.14
A-Treatment (50 weevil/jar)	y	269.58

$$\boxed{W = q_\alpha(t,v)\sqrt{MSE/n_t}} \tag{7}$$

-Levels not connected by same letter are significantly different

Dead weevils

Some dead weevils were observed in each jar (Fig 8), but when the data were normalized to dead weevils per kilogram of dry matter of corn (weevils/kg DM), they all tended to zero. Some of the deaths were likely due to some of the weevils being at the end of their life-span.

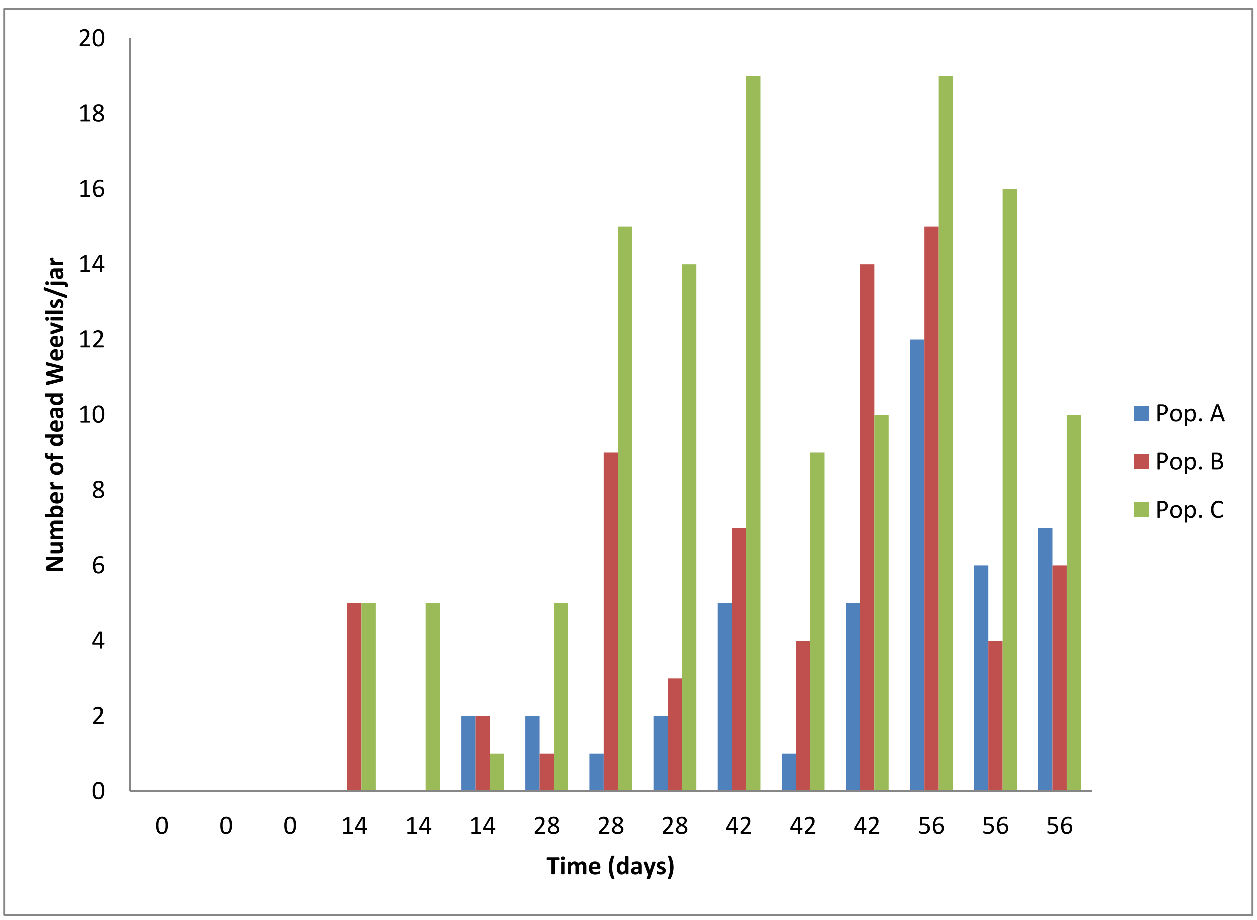

Figure 8: Non-normalized dead weevils observed

Maize moisture content

There was a general decline in the moisture content in all jars (Fig 9) during the experiment. On average the initial moisture content was 13.1%. The initial moisture contents verses final moisture contents at different population densities showed significant differences in means by Tukey's method ($p<0.0001$). The general decline in moisture content was attributed to the environmental chamber in which the experiment was carried out. To establish equilibrium, moisture had to migrate from the grain into the chamber environment.

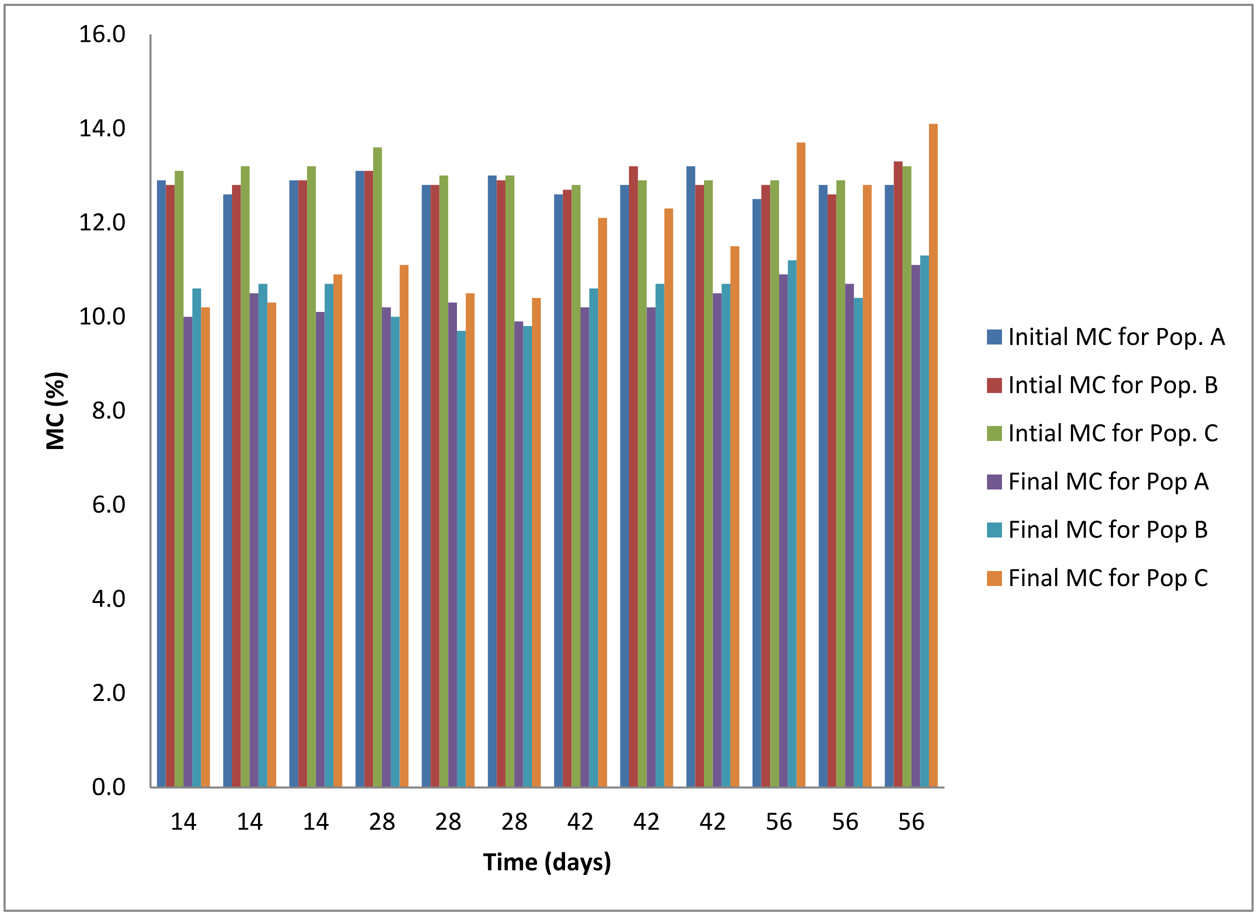

Figure 9: Maize moisture content at different time periods for different population densities

Conclusions

- Maize weevil growth prediction equation was developed.
- Growth constant for weevils is 0.0392 to 0.0448 (t^{-1}).
- Weevils for future research work were raised.
- Exponential growth was observed.

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